

Effect of Staging and Shape in RCC and Precast Elevated Water Tanks

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Abstract

This study explores the effect of staging in RCC (Reinforced Cement Concrete) and precast elevated water tanks, focusing on their design, performance, and safety. Elevated water tanks, integral to water distribution systems, require a robust staging system to ensure structural integrity under dynamic loads, particularly during seismic events. The research examines how various staging configurations RCC and precast affect the overall performance of these tanks. While RCC staging offers higher rigidity and durability, it comes with longer construction timelines and higher labor costs. In contrast, precast systems provide faster construction and cost savings but depend heavily on joint detailing for stability. The study also emphasizes the importance of material properties, seismic design considerations, and load distribution mechanisms. Advanced modeling techniques, including finite element analysis, are employed to assess the structural behavior of both staging systems. The findings aim to optimize the design process, improve safety, and ensure the long-term functionality of elevated water tanks in different environmental conditions.

Keywords: *Elevated water tanks, RCC staging, precast staging, seismic performance, load distribution, structural stability, and finite element analysis.*

1. Introduction

The staging system of elevated water tanks is a fundamental component that dictates the structural integrity, safety, and performance of water storage systems. Elevated water tanks play a crucial role in municipal, industrial, and domestic water distribution, as they provide necessary storage and maintain water pressure for distribution. The staging supports the tank at height, enabling proper water flow and resisting vertical and horizontal forces, including wind and seismic loads. Consequently, the design and configuration of the staging system significantly impact the overall performance and stability of the structure. In reinforced cement concrete (RCC) elevated tanks, staging is usually constructed in situ using columns, braces, and beams arranged in either circular or rectangular patterns. These monolithic structures offer high rigidity, which ensures structural stability; however, they typically require longer construction periods. In contrast, precast elevated water tanks utilize prefabricated components that allow faster installation, ensuring consistent quality and reducing construction time. The performance of precast systems, however, depends heavily on the stability of the joints and connection detailing. The staging design, including parameters such as staging height, bracing patterns, and the number of columns, influences the tank's behavior under both static and dynamic loads. Taller staging increases the flexibility of the structure, resulting in higher lateral displacements. Efficient bracing systems become crucial to control these displacements and maintain stability. Additionally, during seismic or high wind events, the water stored in elevated tanks generates significant dynamic forces on the staging, requiring designs that incorporate adequate ductility, stiffness, and energy dissipation. With advancements in numerical modeling and performance-based design, the understanding of interactions between the staging system and tank behavior has improved, enabling better predictions and safer designs. Studying these effects in both RCC and precast elevated water tanks is essential for optimizing designs, enhancing safety, and ensuring the long-term functionality of water storage systems.



Figure 1: Precast Water Tank (<https://acrobat.adobe.com/id/urn:aaid:sc:AP:7fbf0bde-5555-470f-a564-8a40cf639a04?viewer%21megaVerb=group-discover>)

The image of this RCC elevated water tank highlights the importance of the staging system in maintaining the structural integrity and functionality of water storage facilities. Elevated water tanks like the one shown are critical components in municipal, industrial, and residential water distribution systems. The design and configuration of the staging system, such as the arrangement of the concrete columns and beams, directly impact the stability of the tank, particularly under dynamic loads like seismic or wind forces. This study focuses on comparing the structural behavior of RCC and precast elevated water tanks with different staging configurations to optimize performance, enhance safety, and reduce construction time and costs.

2. Staging in RCC Elevated Water Tanks

Staging in reinforced cement concrete (RCC) elevated water tanks is a critical structural element that supports the tank at an elevated height, providing the necessary pressure for water distribution and resisting vertical and horizontal forces, such as seismic and wind loads. RCC staging is typically constructed in situ using columns, beams, and braces arranged in a grid pattern, offering high rigidity and stability. This monolithic construction ensures durability and the capacity to withstand substantial loads over time. However, RCC tanks generally require longer construction periods due to the on-site pouring and curing processes. The performance of RCC staging depends on key factors such as the height of the staging, bracing configuration, and the material properties of the concrete and reinforcement. Taller staging increases flexibility, potentially leading to higher lateral displacement, which necessitates efficient bracing systems to maintain stability. Overall, RCC staging offers excellent stability but demands careful consideration in seismic design.

2.1 Key Parameters in RCC Staging:

The height of staging in RCC elevated water tanks significantly impacts their structural performance. Taller staging increases the flexibility of the structure, which can lead to higher lateral displacement. This issue can be mitigated by incorporating efficient bracing systems, such as X-bracing or shear walls, which enhance lateral stability, or by using stiffer materials that reduce flexibility. The choice of bracing configuration plays a crucial role in providing the necessary lateral stability. RCC tanks commonly use X-bracing or shear walls, each with its own set of advantages in terms of construction time, cost, and seismic resistance. For instance, X-bracing can be faster to implement, while shear walls may offer greater overall stability, especially in high seismic zones. Lastly, the material properties of RCC tanks, including the

use of high-strength concrete and steel reinforcement, are critical to ensuring the tank's ability to withstand dynamic loads. These materials are particularly essential in seismic zones where the tank must resist the additional forces imposed by earthquakes. Therefore, a combination of adequate staging height, efficient bracing, and robust material choices ensures the stability and safety of RCC elevated water tanks under various loading conditions.

3. Precast Elevated Water Tanks

Precast elevated water tanks utilize prefabricated concrete elements, such as columns, beams, and slabs that are manufactured off-site and assembled at the construction location. Precast staging offers advantages such as faster construction, better quality control, and easier maintenance due to the uniformity of the precast components. However, the performance of precast systems heavily relies on the stability of the joints between the elements, and any weaknesses in the connection detailing could compromise the overall integrity.

3.1 Key Parameters in Precast Staging:

In precast staging, the structural integrity of the connections between precast elements is heavily dependent on column and joint detailing. Precise detailing is crucial to ensure that the joints can withstand dynamic loads, particularly seismic forces. The performance of these joints under seismic loading plays a significant role in determining the overall stability of the precast system. Similar to RCC tanks, the height and flexibility of precast tanks influence their lateral displacement. However, the modular nature of precast systems offers a significant advantage, as it allows for quicker adjustments in design to meet specific load requirements. This flexibility in design enables the system to be tailored more efficiently for different conditions. Additionally, load distribution in precast systems is generally more efficient due to the uniformity and precision of the pre-designed, prefabricated components. This reduces the potential for errors during construction and ensures more consistent structural behavior under both static and dynamic loads. Together, these factors contribute to the enhanced performance and stability of precast elevated water tanks.

4. Comparison of RCC and Precast Staging

The comparison of RCC and precast staging systems in elevated water tanks is crucial for optimizing design, cost, and performance. RCC staging, constructed in situ, offers high rigidity and stability but typically requires longer construction periods and higher labor costs. In contrast, precast staging uses prefabricated components, allowing for faster installation and consistent quality, though it relies heavily on precise joint detailing and connection stability. Both systems are designed to withstand vertical and horizontal loads, but differences in flexibility, load distribution, and seismic performance make it essential to carefully evaluate each system for specific project requirements.

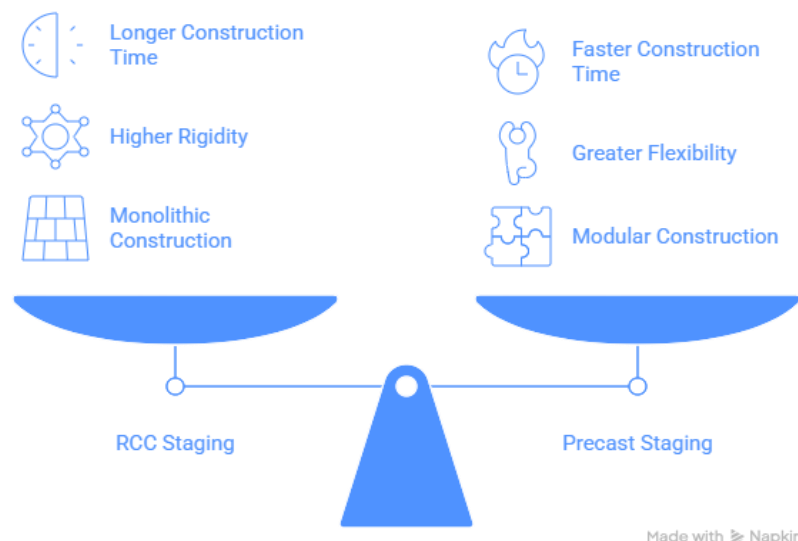


Figure 2: Comparison of RCC and Precast Staging for Optimal Design

4.1 Construction Time and Cost:

RCC (Reinforced Cement Concrete) systems are known for their durability and rigidity, which makes them a preferred choice in areas where long-term structural stability is essential. These systems, however, come with certain drawbacks, notably their extended construction periods and higher labor costs. The in-situ construction process, where the columns, beams, and slabs are cast on-site, often requires more time and skilled labor, leading to increased overall project costs. This can be particularly challenging in large-scale or time-sensitive projects where construction timelines are critical.

On the other hand, precast systems offer significant advantages in terms of construction speed and cost-efficiency. Precast elements are manufactured off-site in controlled factory environments and then transported and assembled on-site. This modular approach allows for faster construction as multiple components can be produced simultaneously, and assembly can begin while other construction activities are underway. Additionally, the use of precast systems reduces the amount of on-site labor required, leading to cost savings. These systems also offer better quality control due to the standardized production processes in factories, ensuring uniformity and reducing the likelihood of errors. For large-scale projects or those with tight deadlines, precast systems present a highly cost-effective alternative, balancing speed, cost, and quality. Despite these benefits, the performance of precast systems still depends heavily on the quality of joints and connections, which need to be carefully designed to ensure structural integrity.

4.2 Seismic Performance

RCC staging systems are known for their higher rigidity, which makes them well-suited for low-seismic regions. The inherent stiffness of RCC structures provides enhanced stability under static loads and reduces the risk of excessive movement. However, in high-seismic areas, this rigidity can become a disadvantage. The lack of flexibility in RCC systems may result in higher lateral displacements and stress concentrations during seismic events, potentially compromising the structure's performance. In contrast, precast systems offer greater flexibility, which can be beneficial in earthquake-prone regions. The modular, prefabricated nature of precast components allows for more controlled deformation during seismic events. This flexibility helps to reduce lateral displacements, mitigating the impact of seismic forces on the tank structure. As a result, precast systems tend to perform more efficiently under dynamic loads, particularly in areas where earthquakes are more frequent and severe.

However, the seismic performance of both RCC and precast systems is not solely dependent on rigidity or flexibility. It also hinges on various design factors, such as the bracing system, column layout, and joint detailing. To enhance earthquake resistance, both systems must incorporate seismic-resistant features like shear walls, damping mechanisms, and reinforced connections. These features improve the ability of the structure to absorb and dissipate seismic energy, ensuring that the tanks remain stable and operational even during intense seismic events.

4.3 Structural Integrity and Durability

RCC systems are widely recognized for their durability and resistance to long-term wear and tear, making them a reliable choice for elevated water tanks. The monolithic nature of RCC staging, where the structure is cast in place as a single unit, significantly enhances its strength and continuity. This monolithic construction minimizes the risk of connection failure, which is a common concern in modular systems. Since the connections between different parts are seamlessly integrated, RCC systems offer better long-term performance and reliability, particularly in demanding environments that experience consistent wear, such as those exposed to harsh weather conditions or frequent loading cycles.

On the other hand, precast systems offer the advantage of high-quality manufacturing in controlled factory settings, ensuring precision and consistency in the components. They also allow for faster construction, reducing project timelines and labor costs. However, precast systems depend heavily on proper joint connection and the quality of materials used. The structural integrity and longevity of precast tanks are largely influenced by the joint detailing and connection performance. If the joints between the precast components are not designed and constructed correctly, or if subpar materials are used, the system may experience deterioration over time, compromising its strength and safety. Despite these concerns, when designed and executed well, precast systems offer an efficient and reliable solution, particularly in projects with tight timelines.

Table 1: Summary of Relevant Studies on Staging Systems in Elevated Water Tanks

Sr. No	Authors / Year	Title	Irregularity Type	Study Method	Key Observation
1	Semiha Kaya and Delvin Salim, 2017	Investigation of Shear Stiffness and Capacity of Joints Between Prefabricated Concrete Elements	Seismic Response and Structural Behavior	Nonlinear Finite Element Analysis (ATENA 3D)	Increased friction and tensile strength enhanced shear capacity; reinforcement in shear keys improved performance; importance of joint detailing and material properties.
2	H. Maneetes and A. M. Memari, 2009	Finite Element Analysis of Architectural Precast Concrete Cladding Systems	Seismic Response and Structural Behavior	Finite Element Method (FEM)	Strong correlation between simulations and tests; precast cladding can resist lateral seismic forces; simplified mathematical model developed for predicting performance.
3	De-Cheng Feng, Cheng-Zhuo Xiong, et al., 2021	Numerical Simulation of Dry Connected Beam–Slab Assemblies in Precast Concrete Structures	Seismic Performance Evaluation	Numerical Modeling (Open Sees)	Thickness of slabs significantly influenced stiffness and energy dissipation; reinforcement ratio had a slight positive correlation with load-bearing and energy dissipation.
4	Ashwini Badhiye, B. V. Bhororia, et al., 2025	Comparative Study on Seismic Behavior of Cast-in-Situ and Precast Staging Structures for Elevated Water Tanks	Seismic Response	Advanced Modeling and Analysis	Precast staging demonstrated comparable seismic resistance to cast-in-situ while offering faster construction and better quality control.
5	Harpreet Singh and Aditya Kumar Tiwary, 2024	Seismic Analysis of Elevated Water Tanks with Composite and RCC Staging	Seismic Performance	Dynamic Analysis	Composite columns improved stiffness and reduced roof displacement, offering better seismic performance than RCC staging.
6	Karanvir Singh Rana, Kundan Kumar, et al., 2015	Seismic Response and Design Considerations of Elevated Water Tanks	Seismic Vulnerability	Seismic Load Analysis	The importance of hydrodynamic pressures and sloshing effects in seismic design was emphasized; failures were often due to improper staging design.
7	O. Kumbhara, R. Kumara, et al., 2019	Performance-Based Seismic Design of Reinforced Concrete Frame Staging for Elevated Water Tanks	Seismic Performance	Nonlinear Time-History Analysis	Modifications to Direct Displacement-Based Design (DDBD) improved seismic reliability and displacement control.

8	Mor Vyankatesh K., and More Varsha T., 2017	Comparative Dynamic Analysis of Elevated Water Tanks with Different Supporting Systems	Seismic Behavior and Stability	Dynamic Analysis using IS 1893	The supporting system significantly affected seismic behavior; improper selection/design of supports leads to failure.
9	Ayub Patel and Sourabh Dashore, 2017	Comparative Seismic Behavior of Square and Circular Elevated RCC Water Tanks	Seismic Performance	Dynamic Analysis using STAAD.Pro	Circular tanks performed better under seismic loads due to greater flexibility compared to square tanks.
10	Kishor Buwade and Vinay Kumar Singh Chandrakar, 2024	Optimization of Design and Construction Practices for Elevated Water Tanks	Structural Optimization and Durability	Advanced Structural Analysis and Design Optimization	Focused on improving seismic resilience, reducing maintenance costs, and extending service life with advanced materials and construction technologies.

5. Performance-Based Design in Elevated Water Tanks

Performance-based design (PBD) represents a significant advancement in the field of structural engineering, allowing for the optimization of elevated water tanks, particularly in terms of safety, material efficiency, and long-term durability. In traditional design approaches, the focus often lies on meeting specific code requirements and ensuring the structure's ability to withstand specified loads. However, PBD shifts the emphasis towards achieving predefined performance outcomes, which could include specific targets for seismic performance, serviceability, and energy dissipation. For both reinforced cement concrete (RCC) and precast elevated water tanks, PBD allows engineers to tailor the design process by considering a wide range of factors, such as seismic response, material properties, and long-term behavior under operational and environmental loads. This approach helps to optimize the use of materials, minimizing waste and reducing construction costs while still ensuring that safety and performance criteria are met. PBD enables engineers to design water tanks that perform optimally under dynamic loads, including seismic and wind forces, by evaluating the expected response of the structure during these events.

One of the primary advantages of PBD is the ability to make more accurate predictions about structural behavior under dynamic conditions. By utilizing advanced computational tools such as nonlinear time history analysis, engineers can simulate how the structure will respond to real-world seismic and wind events. These predictions allow for the design of structures that can withstand extreme loading without over engineering the system, which is often the case with traditional design approaches. For example, by modeling the fluid–structure interaction and considering the sloshing effect in the water tank, PBD can improve the design of staging systems to minimize lateral displacements and prevent structural damage during seismic events. Moreover, PBD considers the long-term durability of materials used in the construction of elevated water tanks. This approach incorporates factors such as fatigue, creep, and corrosion, ensuring that the structure remains functional and safe throughout its service life. Overall, performance-based design enhances the resilience of elevated water tanks, allowing for more efficient and sustainable construction practices while improving the long-term reliability of water storage infrastructure.

5.1 Considerations in Performance-Based Design:

In performance-based design (PBD) for elevated water tanks, one of the critical components is the dynamic load analysis, which involves evaluating the response of the staging system to dynamic forces such as seismic and wind loads. These dynamic loads impose significant stresses on the structure, especially for elevated water tanks, where the height and mass of the tank amplify the effects of such forces. Analyzing how the staging system reacts to these forces is essential to optimize the design for both safety and cost. Dynamic load analysis allows engineers to predict the structural behavior more accurately, ensuring that the tank performs efficiently under real-world conditions without overengineering the

system. It also helps to identify weak points in the design, such as excessive lateral displacement or insufficient bracing, which can be addressed in the design phase to avoid costly retrofits or performance failures in the future. Incorporating energy dissipation features is another crucial aspect of enhancing the seismic performance of elevated water tanks. During seismic events, the water mass in the tank generates significant forces, which are transferred to the staging system. The introduction of energy dissipation mechanisms, such as damping systems, can significantly improve the tank's ability to absorb and dissipate seismic energy. These systems help reduce the forces transmitted to the structure, lowering the risk of structural damage and ensuring the safety and longevity of the water tank. Energy dissipation features are especially beneficial for taller staging systems, where flexibility and displacement during earthquakes are more pronounced. By incorporating damping systems, such as tuned mass dampers or friction dampers, engineers can optimize the design to enhance the tank's performance under dynamic loads, improving its resilience and safety.

Material efficiency is also a critical consideration in PBD, especially in terms of the materials used for the staging system. Advanced materials, such as high-strength concrete and fiber-reinforced polymers (FRPs), can significantly improve the durability and overall efficiency of the structure. High-strength concrete provides greater strength with reduced material volume, which helps to minimize the weight of the structure while maintaining stability. On the other hand, FRPs offer excellent resistance to corrosion, especially in areas with high humidity or exposure to chemicals. By incorporating these advanced materials, the overall cost of construction can be reduced, as less material is needed without compromising the structural integrity or lifespan of the tank. Using these materials also reduces the long-term maintenance costs, as they offer enhanced durability and resistance to environmental factors, ensuring that the elevated water tanks remain reliable and safe throughout their service life.

6. Challenges and Research Gaps in the Design of Elevated Water Tanks

The design of elevated water tanks, whether RCC or precast, involves several challenges that engineers must address to ensure safety, durability, and cost-effectiveness. One of the primary challenges is the dynamic behavior of these structures under seismic, wind, and operational loads. Elevated water tanks are subject to significant lateral forces during seismic events, and their height-to-mass ratio often results in large displacements, leading to potential stability concerns. RCC tanks, though rigid, may suffer from excessive lateral displacement, while precast systems, while offering faster construction, can be prone to connection failures if not designed carefully. The interaction between the water mass and the structure, particularly the fluid-structure interaction (FSI), further complicates the dynamic analysis. Precise modeling of this interaction is crucial to understanding how the tank and staging system will behave under extreme conditions, but it remains a challenge due to the complexity of simulating fluid movements and their impact on the tank structure. Another significant challenge is material efficiency. In traditional RCC tanks, overuse of concrete and reinforcement can lead to higher construction costs, while precast systems often require careful attention to joint detailing and material compatibility. Advanced materials such as fiber-reinforced polymers (FRPs) and high-strength concrete offer promising alternatives, but their adoption is hindered by a lack of standardized codes and guidelines for their use in water tank staging. Although these materials can reduce weight and increase durability, there is limited research on their long-term performance, particularly in seismic-prone areas. Moreover, the cost-benefit analysis of incorporating such materials is still under investigation, with further studies required to optimize the balance between material savings and structural safety.

There is also a lack of standardized seismic design codes for elevated water tanks, particularly for precast systems. Current codes primarily address conventional RCC staging, but the behavior of precast tanks, which rely on joint connections and modular elements, is not fully addressed. Additionally, while performance-based design (PBD) methods have been developed to assess seismic performance more accurately, their application to elevated water tanks remains limited. Many of the existing studies focus on either RCC or precast tanks individually, with few offering direct comparative analyses of both systems under similar seismic conditions. Furthermore, there is a need for research into the long-term behavior of elevated water tanks. Issues such as crack propagation, corrosion, and material fatigue are critical to understanding the true lifespan and durability of these tanks. While there are studies on individual components, a comprehensive approach that integrates all factors—static and dynamic loads, material performance, seismic resistance, and durability—is still lacking. The optimization of joint detailing and connection performance in precast systems remains an under-explored area, which could lead to more robust and efficient designs. In conclusion, while there has been progress in the design of elevated water tanks, numerous challenges and research gaps persist, particularly in understanding the interaction between the tank and the supporting staging system, optimizing material use, and developing standardized seismic design approaches for both RCC and precast systems. Addressing these gaps through further research will be essential to ensuring the safety, cost-effectiveness, and sustainability of these critical water infrastructure systems.

7. Conclusion

The design and performance of elevated water tanks are critical for ensuring the reliable storage and distribution of water, particularly in urban and seismic-prone areas. This review has examined the key factors influencing the structural behavior of reinforced cement concrete (RCC) and precast elevated water tanks, focusing on staging systems, seismic response, material efficiency, and construction time. Both RCC and precast systems have distinct advantages and challenges that must be considered in the design process. RCC staging systems, known for their rigidity, provide excellent stability and are well-suited for regions with low seismic activity. However, their construction typically requires longer periods and higher labor costs. Precast staging systems, on the other hand, offer faster construction times, reduced costs, and better quality control due to their prefabricated components. However, their performance is heavily dependent on the stability of the joints and connection detailing, particularly under dynamic loads such as earthquakes or high winds.

Performance-based design (PBD) has emerged as an essential tool for optimizing the design of elevated water tanks, allowing engineers to tailor the structure to meet specific performance criteria without over-engineering. PBD methods consider dynamic load analysis, energy dissipation features, and material efficiency, helping to balance safety and cost-effectiveness. The use of advanced materials like high-strength concrete and fiber-reinforced polymers (FRPs) shows promise in improving the durability and seismic resilience of elevated tanks. However, several research gaps remain, particularly in the areas of seismic design codes for precast systems, long-term material performance, and the fluid-structure interaction effects on tank stability. Addressing these gaps through further research will enhance the overall safety, efficiency, and sustainability of elevated water tanks, ensuring their reliability in meeting the growing demand for water storage and distribution.

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